Measuring insertion loss of cavities

By Harold Kinley, C.E.T.

How much insertion loss is your cavity causing at the *desired* or *pass* frequency? How does a field technician measure the insertion loss without access to laboratory-type equipment or under field-test conditions? It can be done with reasonable accuracy using some basic methods.

Recently, while surfing the Internet, I came across an interesting application note in the form of a "Tech-aid" called "Measuring Insertion Loss with Wattmeters" from TX RX Systems, Angola, NY. You can find it at www.txrx.com/f3c.html. With permission from TX RX Systems, the document from the Web site is presented here, with minor editing for space considerations. Following the note, I offer some of my thoughts. (On the Web site, Figure 1 and Figure 2 are the same, which is an obvious oversight. So, I added Figure 1 to match the text description of the test setup.)

Measuring Insertion Loss with Wattmeters

Passband insertion loss is a primary specification of a wide variety of passive RF devices. Typical insertion loss values are relatively small and therefore are difficult to measure with anything but laboratory-quality instruments. At TX RX Systems, we measure insertion loss using the latest Hewlett-Packard network analyzers. The calibration of our instruments is traceable to the National Institute of Standards and Technology (NIST) ...

It is not easy to accurately measure low values of insertion loss at high power using ordinary radio transmitters as signal sources and RF wattmeters, such as the Bird model 43 or similar. In fact, insertion loss under power cannot be measured directly; it must be calculated as a ratio of measured RF power at the output and input of the device under test (DUT), using the formula:

$$IL = 10 \times \log (P_o \div P_i)$$

where IL *is insertion loss (in decibels),* Pi *is RF power input at the DUT and* Po *is RF power at output of the DUT.*

This Tech-aid explains why indirect insertion loss measurements made with a single wattmeter are prone to significant errors and describes a two-wattmeter method that is more likely to be in agreement with measurements made with laboratory-quality instruments.

Single-wattmeter method

In general, it is not possible to use a single wattmeter to measure device input and output power with sufficient accuracy to verify factory insertion-loss specifications. There are just too many possible sources of error.

Figures 1A and 1B describe a common method of performing the required power measurements. The DUT has a factory-measured insertion loss of −1.5dB at the pass frequency. The wattmeter is a Bird model 43 with a 50W element, and the transmitter is a 30W mobile transceiver. Random-length coaxial cables are used for equipment connections.

In Figure 1A (below left), the transmitter is connected to the DUT via the wattmeter and test cables 1 and 2. The output of the device is connected to a 50Ω load via cable 3. When the transmitter is keyed, the wattmeter indicates 32.3W forward power. We record Pi *= 32.3W. In Figure 1B (below left), the transmitter is connected to the DUT via cable 1. The output of the DUT is now connected to the load via cable 3, the wattmeter and cable 2. The wattmeter now indicates 20W forward power. We record* Po *= 20.0W.*

With the above power measurements, insertion loss is calculated as follows:

$$\begin{aligned} IL &= 10 \times \log (20 \div 32.3) \\ &= 10 \times (-0.21) \\ &= -2.1\text{dB} \end{aligned}$$

Is this filter out of specification? Before we reach any conclusions, let us take a close look at the possible sources of error inherent to the single-wattmeter method.

Sources of measurement error

▶ Transmitter load impedance changes — *Substantially different lengths of cable are used to connect the DUT to the transmitter in 1A and 1B. If filter input impedance is not purely resistive and equal to 50Ω, changing the length of cable between it and the transmitter can change the magnitude and phase of the load impedance presented to the transmitter. Transmitter output power may therefore change, due to the*

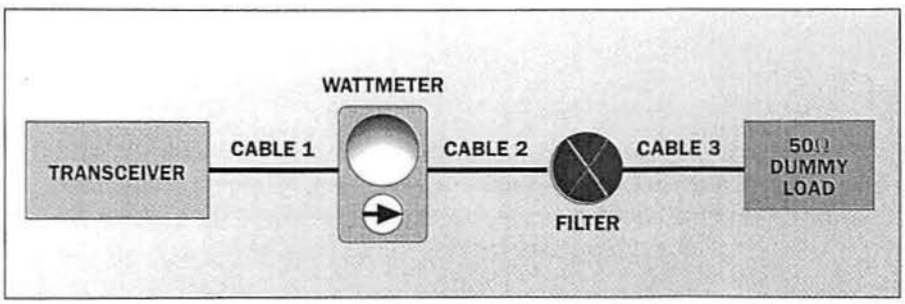

Figure 1A. The wattmeter is positioned on the input side of the filter and the forward power is measured. Random lengths of cable are used.

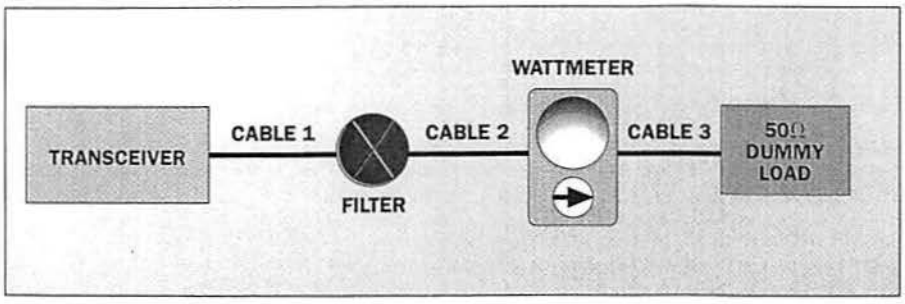

Figure 1B. The forward power on the output side of the filter is measured in this setup.

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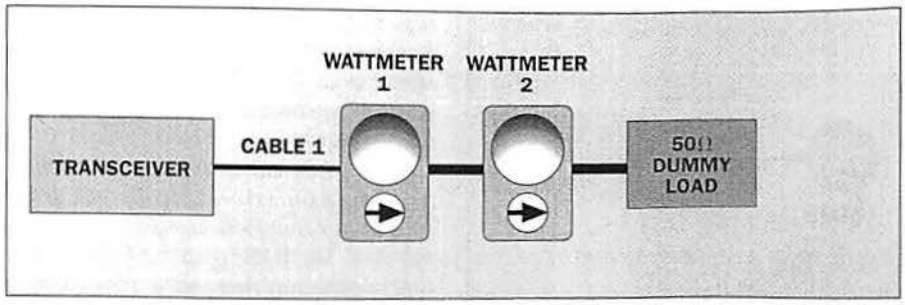

Figure 2A. This setup is used to establish the calibration of the wattmeters and to determine a correction factor.

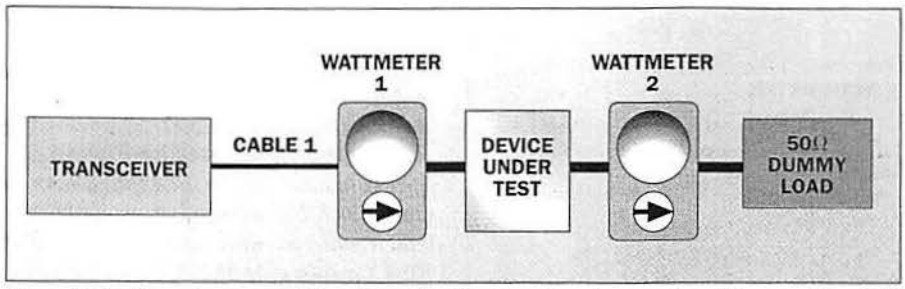

Figure 2B. This setup is used to determine the insertion loss of the filter or other DUT (device under test).

load impedance changes caused by moving the wattmeter and one cable from the input to the output of the DUT.

▶ Wattmeter position — *Standing waves exist in a transmission line that is terminated in a mismatched or reactive load. Depending on the VSWR, different power measurements may be obtained with the wattmeter at different points within the standing wave pattern in the test cables.*

▶ Cable and fitting insertion loss — *The loss of all interconnecting cables and fittings that affect power measurements must be considered in the calculation of insertion loss. The total error ... could easily be about 0.6dB, the discrepancy between factory specification and field measurement ... worse if the test transmitter were unstable.*

▶ Transmitter instability — *Some transmitter power amplifiers may not be stable at all load impedances and phase angles. Resonant devices in particular may exhibit large reactive components at off-resonance frequencies. This may induce parametric oscillations that produce significant output power at frequencies outside the passband of the DUT. If the transmitter is oscillating, a wattmeter measurement of transmitter output power will include spurious power. If spurious power is significantly attenuated by the filter under test, a "false insertion loss" will result. Depending on the ratio of spurious to carrier power, and the response of the DUT, even larger insertion loss measurement errors may be induced.*

In Figure 1C [not shown], the transmitter oscillates when it is connected to the DUT via a shorter, unfavorable length of cable. The wattmeter on the filter output reads only 15.5W forward power, because about 4.5W of spurious power are not passing through the cavity

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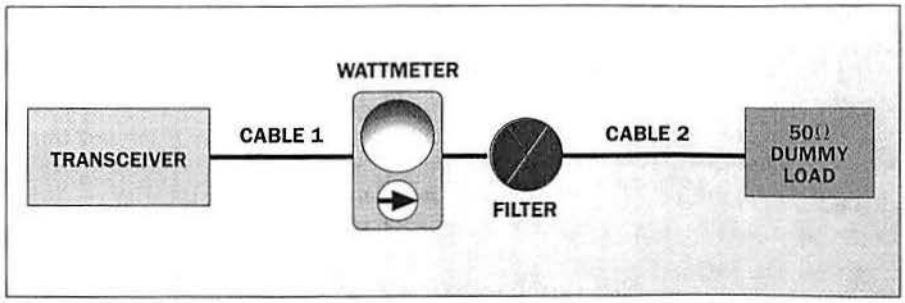


Figure 3A: This single-wattmeter method of measuring insertion loss is valid as long as proper attention is paid to cable lengths. The input power to the filter is measured here.

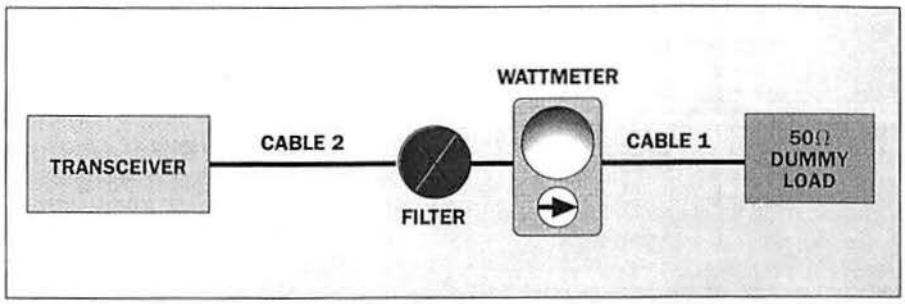


Figure 3B: The output power from the filter is measured here. Cable lengths of one-half wavelengths (or multiples) are maintained in this procedure.

filter. Insertion loss now appears to be:

$$IL = 10 \times \log (15.5 \div 32.5)$$
$$= 10 \times (-0.32)$$
$$= -3.2dB.$$

This result is completely wrong.

Recommended test method

TX RX Systems recommends a two-wattmeter, two-step method that eliminates most of these problems. The arrangement in Figure 2A (see page 49) is first used to obtain wattmeter readings to correct for test equipment insertion loss and wattmeter relative calibration errors. The setup in Figure 2B (see page 49) is then used to measure input and output power.

Cable 1 is cut to a length such that total transmission line length from transmitter output to the wattmeter output is a multiple of a ½-wavelength (λ/2) at the test frequency. This ensures that the load impedance "seen" by the transmitter is essentially the same as the impedance of the DUT connected to wattmeter 1. Wattmeter operating manuals usually contain information on optimal lengths of cable required for various frequency ranges.

In Figure 2B, wattmeters 1 and 2 are connected directly to the input and output of the DUT, using a short cable or a type N male-to-male union (UG-57B/U, TX RX part no. 8-5857). It may also be necessary to use a type N, 90° male-to-female adapter (UG-27C/U, TX RX part no. 8-5867) to facilitate installation of the wattmeters near the DUT. In Figure 2A, the wattmeters are connected using the same fittings as in Figure 2B, plus an additional type N female-to-female union (UG-29B/U, TX RX part no.8-5856).

The 50Ω load resistor in Figures 1 and 2 should be connected to the output of wattmeter 2 via a short length of coaxial cable or a type N male-to-male union. The length of transmission line between the wattmeter and the load resistor is not critical if return loss is −30dB or better.

Test procedure

1. *Connect wattmeter 1 directly to wattmeter 2 as shown in Figure 2A. Key the transmitter and record the forward power readings, P1 and P2.*
2. *Unkey the transmitter and insert the DUT between wattmeters 1 and 2, as shown in Figure 2B.*
3. *Key the transmitter again and record the forward power readings, P3 and P4.*
4. *Calculate insertion loss as follows:*

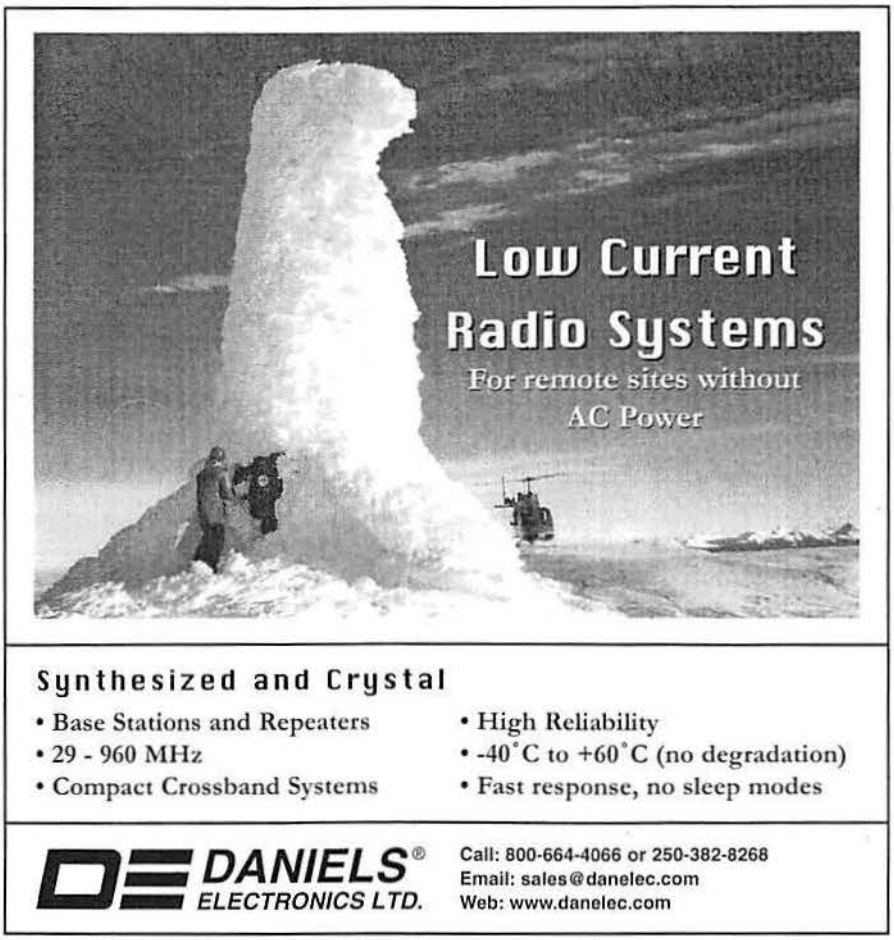
$$IL = 10 \log ((P1 \times P4) \div (P2 \times P3)).$$

The following measurements are obtained with the cavity filter in the previous example: P1 = 28.7W; P3 = 28.0W; P2 = 24.0W; and P4 = 16.8W.

Computed insertion loss is:

$$Po \div Pi = (28.7 \times 16.8) \div (24.0 \times 28.0)$$
$$= 0.7175$$
$$IL = 10 \log (0.7175)$$
$$= -1.44dB$$

This is within less than 0.1dB of the factory specification for the filter under test.



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In case of a discrepancy, if you use the suggested two-wattmeter method and your insertion loss measurement does not agree with ours, there are two likely causes: Either your transmitter is oscillating, or our equipment is indeed out of specification.

With the equipment arranged as in Figure 2B, insert a −30dB RF sampler on the transmitter output and check the transmitter spectral purity with a spectrum analyzer. Carefully scan a broad frequency range, as spurious outputs may sometimes appear at frequencies far removed from the carrier. If the transmitter is clean, it is safe to conclude that the equipment is out of specification. You should then file a warranty claim.

Other precautions

1. *Use wattmeter elements that produce a wattmeter reading at mid-scale or higher.*
2. *Use the best cable and connectors money can buy. If possible, connectors should be crimped and soldered. A bad connector will ruin your measurement.*
3. *Do* not *use UHF connectors or adapters. UHF connectors are notorious for their bad impedance characteristics even at VHF frequencies. Put type N connectors on your wattmeter.*
4. *Check the spectral purity of your test transmitter. All spurious products and harmonics must be at least 60dB to 70dB below the carrier when the transmitter is loaded as in Figure 2B.*

Brief observations

The points made by this application note are well worth remembering and following. I would like to comment on a couple of points. Concerning the wattmeter position along the line, the note stated that *"Depending upon the VSWR, different power measurements may be obtained with the wattmeter at different points within the standing wave pattern in the test cables."* Specific mention was made of the Bird model 43 wattmeter. The Bird 43 instruction book, page 2-0, states *"Being highly directional, the Thruline Element is sensitive at one setting only to one of the traveling waves, which produce standing waves by interference. Thruline measurements are therefore independent of position along standing waves. It may be said that the Thruline doesn't know, doesn't care and doesn't need to care where it is along a standing wave."*

Because any spurious signal would affect the single-wattmeter method of measuring insertion loss, it would also affect the two-wattmeter method. The two-wattmeter method gives no advantage in this regard.

Single-wattmeter method

I am not arguing against the two-wattmeter method of performing the insertion loss test. However, if only one wattmeter is available, there is a way to use a single wattmeter to measure the insertion loss of a filter with a reasonable degree of accuracy. Refer to Figures 3A and 3B on page 50.

In Figure 3A (assuming N connectors throughout), the wattmeter is connected to the filter input directly using an N male-to-male connector. The length of cable 1 is chosen such that:

cable 1 + wattmeter through-line section + N male-to-male connector

is equal to λ/2 (or a multiple thereof) at the operating frequency. The type N male-to-male connector is used to connect the wattmeter directly to the filter in both Figures 3A and 3B. The velocity factor of the cable must be taken into account when calculating the cable length. Assuming that all the lines between the transmitter output and the filter input total λ/2, or a multiple thereof, the input impedance of the filter will be seen by the transmitter output.

Cable 2, connecting the filter output to the dummy load, is also cut to λ/2 (or a multiple).

With the setup in Figure 3A, the transmitter is keyed and the forward power reading is recorded. Record this measurement as P_i. Also take a look at the reverse power reading to check for a severe impedance mismatch. Now, using the setup shown in Figure 3B, key the transmitter and record the wattmeter reading as P_o. Notice that in Figure 3B, cable 2 connects the transmitter to the filter input. The line length is still λ/2, so the impedance seen by the transmitter has not changed.

Using the readings, you can determine the insertion loss by the formula:

$$IL = 10 \log (Pi \div Po).$$

If $Pi = 40W$ and $Po = 30W$, then the insertion loss of the filter is:

$$10 \log (40 \div 30) = 10 \log (1.333) = 1.25dB.$$

All precautions stated for the two-wattmeter method apply to the one-wattmeter method as well. Reasonable care in setting up the test procedure will yield reasonable accuracy in the result.

Until next time—*stay tuned!* ■

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